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EFFECT OF EXHAUST OF F-100A AIRCRAFT ON AIRFIELD PAVEMENTS. SUMMARY OF RESULTS OF TESTS AT DAVIS-MONTHAN AIR FORCE BASE, ARIZONA

Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

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CORPS OF ENGINEERS, U. S. ARMY

EFFECT OF EXHAUST OF F-100A AIRCRAFT ON AIRFIELD PAVEMENTS

SUMMARY OF RESULTS OF TESTS AT DAVIS-MONTHAN AIR FORCE BASE, ARIZONA

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MILITARY CONSTRUCTION

BY

WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

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CONTENTS

EFFECT OF EXHAUST OF F-100A AIRCRAFT ON AIRFIELD PAVEMENTS

SUMMARY OF RESULTS OF TESTS AT DAVIS-MONTHAN AIR FORCE BASE, ARIZONA

PART I: INTRODUCTION

1. The selection of the type or composition of pavements which will satisfactorily withstand the heat, blast, and fuel spillage from jet aircraft has been the subject of considerable study during the past several years by the Corps of Engineers at the request of the U. S. Air Force. This study is necessarily of a continuing nature owing to constant developments in aircraft design and propulsion units. One report issued to date covered time movement of aircraft under normal operational conditions, temperatures induced in pavements, and effects on pavements caused by operations of the F-80, F-84, F-86, F-89, F-94, T-33, B-45, and B-47 aircraft on both asphaltic-concrete and portland-cement-concrete pavements[(1)]. In addition, comparative studies of the effect of F-80 and T-33 aircraft on asphalt, tar, and tar-rubber-concrete pavements have been made[(2)]. Current studies at the Waterways Experiment Station consider the effects of traffic and fuel spillage as well as heat and blast on flexible pavements, and studies at the Rigid Pavement Laboratory consider similar effects on concrete pavement.

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(1) "Study of Effect of Current-type Jet Aircraft on Airfield Pavements, Interim Report on Heat and Blast Effects on Pavements," published by the Waterways Experiment Station, Corps of Engineers, U. S. Army, December 1952.

(2) "Heat and Blast Effects on Tar and Tar-rubber Pavements, Presque Isle Air Force Base, Maine," T.M. No. 3-377, Waterways Experiment Station, Corps of Engineers, U. S. Army, January 1954.

2. Previous tests to determine the effect of jet blast on airfield pavements and to measure temperatures of the pavements have been made for the most part with single-engine jet aircraft having propulsion units developing about 5000 lb thrust and without afterburners. The purpose of the tests summarized herein was to determine the effect of the exhaust blast on pavements and to measure pavement temperatures during operations of the F-100A aircraft. The J57-P-7 propulsion unit of the F-100A aircraft develops considerably higher thrust than planes previously tested and is equipped with an afterburner. The types of pavement for consideration were asphaltic concrete, tar-rubber concrete (two types), and portland-cement concrete.

3. The tests were authorized in letter from the Office, Chief of Engineers (ENGER), dated 24 June 1954, subject "Effect of Exhaust of F-100 Aircraft on Airfield Pavements." The request for the tests was made in letter from the U. S. Air Force dated 18 June 1954, same subject. Subsequent correspondence under the same subject delineated the proposed test program and other details pertinent to the accomplishment of the desired tests.

4. The accomplishment of the test program at Davis-Monthan Air Force Base during the period 8-16 July 1954 was a co-ordinated effort of the Air Force Flight Test Center at Edwards Air Force Base, California; the Strategic Air Command at Davis-Monthan Air Force Base, particularly the Air Installations and Base Operations groups; the Corps of Engineers' South Pacific Division, Los Angeles District, and Davis-Monthan Air Force Base Project personnel; and the Flexible and Rigid Pavement Laboratories of the Corps of Engineers. Specific personnel assisting in preparation

for and conduct of the tests and observers for the U. S. Air Force, the Corps of Engineers, and other groups are listed in attachment hereto. In addition, supervisory personnel of the Office, Chief of Engineers and the Flexible Pavement Laboratory were active in planning the tests. This report was prepared jointly by the Rigid and Flexible Pavement Laboratories of the Corps of Engineers.

PART II: DESCRIPTION OF PAVEMENTS

5. All of the Davis-Monthan Air Force Base pavements selected for these tests were constructed during the past year under the supervision of the Corps of Engineers with the District Engineer, Los Angeles, California, as contracting officer. Direct supervision of the construction was exercised by a project engineer assigned to Davis-Monthan Air Force Base.

6. The asphaltic-concrete pavement selected for test was the east lane of the NW-SE taxiway (No. 14) approximately 300 ft northwest of the junction of taxiway 14 and the alert hangar apron. This section of pavement was approximately nine months old at the time of test, construction having been completed in October 1953. Pertinent test-properties data for the surface course are tabulated below.

Aggregate

Type and Source	Grading (Average) Sieve Size	Per Cent Passing
Crushed gravel (75 per cent fractured faces) from the Pantano Wash, a few miles east of Davis-Monthan Air Force Base	3/4 in.	100
	1/2 in.	94
	3/8 in.	86
	No. 4	66
	No. 10	49
	No. 20	35
	No. 40	23
	No. 80	12
	No. 200	5

Marshall (Plant Control) Properties

	Average	Range
Asphalt* content, per cent	6.7	6.6 - 6.8
Stability, lb	1490	1250 - 1730
Flow	9	7 - 10
Voids, total mix, per cent	5.3	5.0 - 5.7
Voids filled with AC, per cent	73.8	72.1 - 74.7
Field compaction, per cent of laboratory	-	-

*85-100 Penetration

7. The tar-rubber-concrete pavements selected for these tests were those comprising the maintenance apron at the southeast end of the NW-SE taxiway (No. 14). This pavement was approximately nine months old at the time of test, construction having been completed in October 1953. In this construction, for comparative test purposes Surfa-aero-sealz tar-rubber was used in the northwest half and Flintbinder C-2 tar-rubber was used in the southeast half. Criteria for 200-psi tires were met by both pavements, and the degree of field compaction was good. Pertinent data for both mixes are tabulated below.

Aggregate

Type and Source	Grading
Same as for asphaltic concrete (see paragraph 6 above)	Same as for asphaltic concrete (see paragraph 6 above)

Marshall (Plant Control) Properties

	Surfa-aero-sealz	Flintbinder C-2
Tar-rubber, per cent	7.5	7.5
Stability, lb	2000	2700
Flow	13	14
Voids, total mix, per cent	5	4
Voids, filled, per cent	75	78
Field compaction, per cent of laboratory	98 - 99	99

5. The section of portland-cement-concrete pavement selected for these tests was a portion of the main B-47 parking apron which extends southeast from intersection of taxiways 14 and 18 to about 1000 ft from the intersection of taxiways 14 and 17. The specific area of the apron used for these tests was in the outer northeast lane approximately 300 ft from the east corner. This pavement was approximately five months old at the time of test, constructing having been completed in February 1954. Field laboratory tests showed compliance with the flexural strengh requirements of the project specifications. Concrete-mix design data are given below.

Aggregate:	Crushed gravel from the Pantano Wash.
Cement:	Type I, Arizona Portland Cement Company, Rillito, Arizona.
Air-entraining Agent:	"Darex," 1 oz per 94 lb of cement.
Water Content:	4.5 gal per 94 lb of cement.
Mix Proportions (by weight):	1:1.648:3.351
Entrained Air:	3.5 - 4.0 per cent

PART III: TEST PROGRAM AND INSTRUMENTATION

9. In the initial program of tests proposed by the Flexible Pavement Laboratory, the program outlined was directly responsive to the exposure conditions stated by the U. S. Air Force in their request to the Office, Chief of Engineers. In addition to the requested test conditions, a "pretake-off" test was added with the approval of the Office, Chief of Engineers and Headquarters, U. S. Air Force. During the test-planning conference at Air Force Flight Test Center, Edwards Air Force Base, California, on 7 July 1954, certain modifications to the originally proposed program were made because of permissible operating times of the F-100 jet engine and in an effort to complete the desired tests in the shortest possible time. Conferees at this meeting included representatives of the Air Force Flight Test Center, Davis-Monthan Air Force Base, North American Aviation, Inc., and Corps of Engineers, U. S. Army. The test program stated hereinafter was approved by the representative of Headquarters, U. S. Air Force on arrival at Davis-Monthan Air Force Base.

10. Results of tests at Eglin Air Force Base (paragraph 1) have shown that the "maintenance run-up" imposed the most severe normal exposure conditions. The starting run-up was found to develop low pavement temperatures and was not considered pertinent in current tests. However, the pretake-off run-up was considered pertinent because the afterburner on the F-100 is used. Power terminology for the F-100 plane differs somewhat from that used in reference to planes tested at Eglin Air Force Base. What was previously considered full power is called "military power" for the F-100 or 100 per cent of jet engine power.

"Full power" for the F-100 plane is military power plus afterburner. These power terms are so used throughout this report. The originally proposed series of tests included the following pavement exposure conditions:

<u>a</u>. Pretake-off with afterburner (full power).

<u>b</u>. Maintenance run-up, 21-minute cycle without afterburner (military power).

<u>c</u>. Maintenance run-up, 21-minute cycle with afterburner (full power).

<u>d</u>. Five minutes at 100 per cent power without afterburner (military power).

<u>e</u>. Five minutes at 100 per cent power with afterburner (full power).

11. The adopted procedure for the F-100A tests on the asphaltic-concrete, tar-rubber-concrete, and portland-cement-concrete pavements included only three exposure conditions and was in accordance with the time cycles shown in the following table.

	Exposure Time			
	Power Setting			
Test Condition	Idle[1]	Military[2]	Full[3]	Total Time
Pretake-off[4]	1 min	15 sec	1-2 sec	1 min 17 sec
Maint. run-up				
Cycle No. 1	5 min 30 sec	1 min 30 sec	-	
Cycle No. 2	5 min 30 sec	1 min 30 sec	-	
Cycle No. 3	5 min 30 sec	5 min (5)	-	24 min 30 sec
Shut-off	5 min			29 min 30 sec
Maint. run-up				
Cycle No. 1	5 min 30 sec	10 sec	1 min 20 sec	
Cycle No. 2	5 min 30 sec	10 sec	1 min 20 sec	
Cycle No. 3	5 min 30 sec	10 sec	5 min (5)	24 min 40 sec
Shut-off	5 min			29 min 40 sec

(1) 65 per cent of jet engine power.
(2) 100 per cent of jet engine power.
(3) 100 per cent of jet engine power plus afterburner.
(4) Time in accordance with procedure used at AFFTC, Edwards Air Force Base, for F-100A aircraft.
(5) Final period at military and full power extended to 5 minutes at the request of USAF, thus combining two separate tests initially proposed.

12. The above-programmed tests were all conducted with the plane held at deadstand by the plane brakes and anchored chocks specially provided for these tests. The use of anchored chocks in these tests was necessary since, owing to the high thrust developed at full power, the normally-used wooden chocks and the plane brakes would not prevent movement of the aircraft. Photograph 1 shows the special chocks (supplied by North American Aviation, Inc.) and anchors with load wheels in place for a blast test. The anchor in front of each chock is steel rail tied down with 1-in.-diameter steel pins driven 5 ft into the ground through flexible pavement. Holes were drilled in concrete pavement for placement of similar anchors.

13. Pavement temperatures were to be determined by means of a minimum number of thermocouples installed within the predetermined

center-of-heat pattern. Accordingly, seven thermocouples for each type of pavement were made at the Waterways Experiment Station from 20-gage iron constantan wire by crimping the bare ends together and silver-soldering. A Brown "Electronik" potentiometer capable of recording up to 1000°F at the rate of once each 12 to 15 sec for each thermocouple was provided by the Waterways Experiment Station. A portable generator furnished by the Air Installations Office, Davis-Monthan Air Force Base supplied power for the recorder.

14. Correct positioning of the thermocouples was accomplished by placing them in saw kerfs cut in the form of a cross pattern and approximately 2 in. deep. The kerf in the direction of the blast, parallel to the paving lanes, was 10 ft long, while the kerf normal to the blast was 4 ft long and intersected the kerf in the direction of the blast at the mid-point. Five thermocouples were installed in the center portion of the cross pattern equally spaced 18 in. apart and one thermocouple was installed at each end of the longitudinal kerf 4.5 ft from the center point. All thermocouples were placed by hand as near as possible at the surface and the kerfs backfilled with final surface positioning of the thermocouples accomplished during the backfilling operation. A cold-mix asphalt surface material (passing the No. 4 sieve) was used for the asphaltic and tar-rubber-concrete test areas and a fine sand-portland-cement mortar (2:1) was used for the portland-cement concrete.

PART IV: TESTS AND TEST RESULTS

15. All pavement tests with the F-100A, outlined in paragraph 11, were completed during the period 13-15 July 1954. A typical test setup with the aircraft in position with the necessary starting energizers is shown in photograph 2. All tests were conducted with as near as practicable full fuel load. Unavoidable minor delays resulted from (a) failure of one of the overheating indicators in the aircraft which necessitated the removal and replacement of the tail section, and (b) the malfunctioning of the "Electronik" recorder.

16. The sequence of testing differed slightly from that stated in the program except in the tests of the portland-cement concrete. This deviation was deemed advisable to permit the conduct of the tests in the order of the exposure conditions believed to be least destructive and thereby obtain the maximum amount of correct pavement-temperature data possible. It is also to be noted that at the completion of test cycles which ended with either military or full power, the standard operating procedure for the J57-P-7 engine requires that the engine continue to run at idle power for five minutes.

17. In addition to the originally programmed tests, two special "pretake-off" tests were made on the asphaltic-concrete taxiway at the request of representatives of Headquarters, U. S. Air Force. These tests were to observe the effect of cutting in the afterburner (a) as the plane brakes were released, and (b) after the plane had moved about 60 ft under military power.

18. Observations and measurements of fuel spillage were made throughout the test period.

19. Results of the tests that were conducted, including pertinent characteristics of the plane, observations of effects on pavements, deviations from the test program, and other significant information, are summarized in table 1. Typical time-vs-temperature curves for the pretake-off, maintenance run-up without afterburner, and maintenance run-up with afterburner test conditions are shown on plate 1.

Tests on Portland-cement Concrete

20. The portland-cement-concrete pavement selected for the test area is not considered truly representative of high-quality concrete pavements. Operations at Davis-Monthan Air Force Base necessary because of the current construction program limited the test-site possibilities to the area described in paragraph 8; however, in this general area a site was chosen which exhibited a minimum of the abnormal surface condition. This abnormal surface condition consists of an over-all surface crazing and is probably due to delay in applying the curing medium during the construction of the parking apron. Time did not permit obtaining cores to determine the depth of this crazing, but it appeared to be purely a surface phenomenon. Since this pavement was only about five months old, little of the curing compound and surface laitance had been removed by the traffic over the area.

21. The initial test on the portland-cement concrete was a pretake-off operation consisting of 1 minute at idle (65 per cent) power, 15 sec at military (100 per cent) power, and 2 sec at full power (military power plus afterburner). The measured height at the center line of the tailpipe for this test was 58 in., which is the rated static height. The pavement-surface temperature at the start of the test was 110°F, and the

ambient temperature 98°F, with the wind ESE at 12 miles per hour. It is to be noted that all tests on the portland-cement concrete were made with the plane on a northwest heading. During the three tests on portland-cement concrete the prevailing winds were almost directly into the tailpipe; therefore, some portions of the recorded pavement temperature curves, particularly when measurements were made at idle power, may be slightly low but not significantly so. The maximum pavement surface temperature recorded was +300°F, which resulted in a pavement-surface temperature rise of +190°F. The stabilization speed of the recorder being used was not sufficiently rapid to obtain the momentarily higher temperatures which probably were reached during the 1-2 sec afterburner blast on a pretake-off test, but indications were that the temperature did not exceed 400°F. Other pertinent information on this test is given under Test No. D-1 and the footnotes thereto in table 1. The temperature-vs-time curve for the pretake-off blast shown on plate 1 is drawn from data collected in this test. No change (paragraph 19) in the pavement surface appearance could be observed at the completion of this test.

22. The second test (D-2) on the portland-cement concrete was the maintenance run-up without afterburner (paragraph 11). This test cycle was the same as that used for the Eglin Air Force Base tests, except that the final period at military power was 5 minutes instead of 1.5 minutes. The ambient temperature, wind velocity and direction, and height of tailpipe at the center line was the same as for Test No. D-1. Pavement-surface temperature at the start of the test was 130°F. The maximum temperature recorded for this test was 295°F during the final 5 minutes at military power, which was a pavement-surface-temperature rise of 165°F. During the

three 5.5-minute periods at idle power the pavement-surface temperature stabilized at about 200°F. Other pertinent information on this test is given under Test No. D-2 and the footnotes thereto in table 1. No visible change from the original surface condition of the pavement could be discerned at the completion of this maintenance run-up test, except for a very slight darkening of the surface in the high-heat area. This slight change in color of this surface was probably owing to a combination of factors such as the small amount of curing compound remaining, removal of laitance, and the dark exhaust gases at military power.

23. The third and final test (D-3) on the portland-cement concrete was a maintenance run-up with afterburner (paragraph 11). The time cycle for this type of test differs from the maintenance run-up cycle for the previous test in that about 10 sec are required to change the throttle from idle to military power before cutting in the afterburner. The measured tailpipe height at the center line was 58-3/4 in. for this test. The pavement-surface temperature at the start of the test was 150°F and the ambient temperature 103°F, with the wind ESE at 12 miles per hour. During the test period the wind direction changed from ESE to SE to S. The wind velocity and direction are not too important while plane is running at full power because the gas velocity 30 ft from end of tailpipe is about 470 miles per hour. The maximum pavement-surface temperature measured during this maintenance run-up with afterburner was 735°F during the final 5-minute period at full power, which resulted in a temperature rise of 585°F. The temperature build-up in the pavement during this test will be noted from the following table of surface temperatures at various intervals. The typical temperature-vs-time curve for maintenance run-up with afterburner shown on plate 1 is drawn from data collected during this test.

Cycle No.	Surface Temperature, °F: Stabilized at Idle Power	Maximum with Afterburner
1	200	660
2	230	670
3	255	735
	255*	

*Ten minutes after engine shut off.

24. There was no erosion of the portland-cement-concrete pavement surface at the completion of Test No. D-3. The intensity of discolored area in the center of the heat pattern had increased appreciably and was an elliptical area approximately 4 by 15 ft. Photograph 3 shows the intensity and area of the discoloration. The surface crazing which was noted in the pavement in the vicinity of the test area prior to the tests, but which appeared to be at a minimum in the test area itself, was greatly accentuated at the completion of this test, and a close-up of the surface appearance is shown in photograph 4. It is hoped that final evaluation of the effect of prolonged afterburner blast (thermal shock) can be made by means of tests with the interval timer, examination of cores taken from the exposed area, and periodic visual inspection of the pavement.

Tests on Tar-rubber Concrete

25. Performance of the two tar-rubber pavements (Surfa-aero-sealz and Flintbinder) was similar for a given test condition to the extent that results of tests on each can be described together. Details concerning the results are given under Tests Nos. B-1, B-2, B-3, C-1, C-2, and C-3 in table 1. It should be noted that the pavement surfaces were in good condition and that a crust (typical of tar pavements) had formed during the

nine-month period since construction. This crust did not appear to be as thick and as brittle as that on test pavements at the Waterways Experiment Station where only 5.6 per cent tar-rubber was used in the mix compared to 7.5 per cent in these pavements. The difference in optimum tar-rubber content is attributed to variation in aggregate type. The pavements selected for test on the maintenance apron have not been used except by a few transient F-86 and T-33 planes.

26. The pretake-off tests (B-1 and C-1) were run in accordance with the power cycle schedule previously described. The test on Surfa-aero-sealz was run in the cool of the morning, whereas the test on Flintbinder was run in the heat of the day, but the same results were obtained. Further, there was a mild cross wind in both instances (4 to 6 miles per hour). The temperature recorder "froze" at a point between 300 and 400°F in each case during the 2-sec period while the afterburner was on. The afterburner caused an area of the pavement about 2 ft wide and 18 ft long to assume a little darker color (very slight melting of bitumen at the surface) than the already rather dark pavement. There was no erosion. The color contrast was not great enough to illustrate by photograph.

27. The maintenance blast without afterburner on Flintbinder (Test No. C-2) covered the prescribed power cycles. There was no visible change in the pavement from the original surface condition. The maximum surface temperature of 280°F was recorded near the end of the final 5-minute cycle at military power, resulting in a temperature rise of 170°F which is comparable to the 165°F rise in Test No. D-2 on portland-cement concrete. The data from this test were utilized in drawing the typical temperature-vs-time curve shown on plate 1 for maintenance blast without afterburner.

A similar test on Surfa-aero-sealz (Test No. B-2) was stopped after 1 minute at military power in the third cycle because of indication on the plane's instruments of high tailpipe temperature. Pavement temperature had reached 265°F and there was no indication of detrimental effect on the pavement. Therefore, the test was not repeated to get a full 5-minute period at military power since the maximum temperature for this type of test on tar-rubber had been obtained on the Flintbinder item and the longer blast had not affected that pavement.

28. The maintenance blast with afterburner on the two tar-rubber pavements was for the same power cycles, namely 5.5 minutes at idle power, 10 sec at military power, and 45 sec at full power. The proposed cycles listed in paragraph 11 were not completed because the pavement eroded. It was not considered worthwhile to continue the blast because the exposed thermocouples were recording gas rather than pavement temperature and continued erosion would require patching of the test area. Erosion started in both tar-rubber pavements about 5 sec after the afterburner was cut in and the areas after 45 sec at full power were 48 ft by 7 ft by 5/8 in., and 45 ft by 6 ft by 1/2 in. for Flintbinder and Surfa-aero-sealz, respectively. Gas temperature measured through exposed thermocouples was about 680°F. True pavement temperature is estimated to be about 600 to 625°F. Photograph 5 shows the shape and condition of the eroded area in Surfa-aero-sealz at the end of Test No. B-3.

Tests on Asphaltic Concrete

29. The asphalt pavement on the southeast end of taxiway 14 near the tar-rubber alert apron was nine months old but had received very little use. The surface texture was good and the pavement had assumed a light color from weathering in contract to the dark color of the tar-rubber pavements. The asphalt content of 6.7 per cent in the surface course is higher than that required for many aggregates in other areas of the United States where 5.0 to 5.5 per cent asphalt is generally used. However, voids properties of the plant mix meet 200-psi design criteria and it is understood that high density was obtained in field rolling.

30. The pretake-off test (A-1) on asphalt was made in accordance with the power cycle utilized for tests on the other three pavement types. However, the area where thermocouples had been installed was not used owing to pavement erosion during the maintenance blast without after-burner which was run first. Therefore, the plane was spotted along the center line of the taxiway without chocks and anchors in front of the load wheels and the pilot was requested to go through the pretake-off operations just as he would if he was taking off. This was possible because the taxiway was closed and there was more than 1000 ft of clear distance over which the plane could roll and the pilot could cut his power and stop within that distance. The test was made in a satisfactory manner with the period of time while the afterburner was on before the plane moved being reasonably the same as when chocks were used and the afterburner cut off after 1 to 2 sec. The effect on the pavement was to darken (very slightly melt) the surface over an area about 2.5 by 18

ft as shown in photograph 6. There was no erosion or free bitumen at the surface, just as in Tests Nos. B-1 and C-1 on tar-rubber pavements.

31. The special pretake-off test referenced in paragraph 17 was requested by Col. R. L. Clifford of Headquarters, U. S. Air Force to see if a darkened area would appear on the asphalt pavement if the plane was made to start rolling before the afterburner was cut in. The pilot was able to follow this procedure without difficulty, letting the plane roll about 60 ft at military power before cutting in the afterburner. Inspection of the area after the test showed that there was no effect on the asphalt surface.

32. The maintenance blast without afterburner was run in accordance with the power cycles listed in paragraph 11. The test was made at about 11 A.M. when ambient temperature was 96°F, surface pavement temperature was 140°F, and the wind was calm. During the first 1.5-minute period at military power numerous small spots of bitumen and aggregate burst out of the pavement at 290°F. During the second 1.5-minute period at military power definite but shallow erosion took place at 295°F. During the third period at military power erosion covered a wider area and the temperature at three thermocouples within that area was recorded at 295°F. This condition was noted within the first 1.5 minutes of the period which would consummate a normal plus 50 per cent maintenance blast as defined in previous time-movement studies. So, the test was simply allowed to continue for the full 5-minute period at military power with the result that the final eroded area was approximately 15 ft by 3.5 ft by 1/2 in. deep. It should be pointed out that the gas velocity developed by the F-100 plane at military power is about

320 miles per hour near the center of heat pattern 30 ft behind the tailpipe as compared to 260 miles per hour by earlier fighter planes 25 ft back of the tailpipe. Also, the diameter of the tailpipe is 22 in. as compared to 19 in. on earlier planes.

33. The maintenance blast with afterburner was necessarily made at another location on the asphalt taxiway, and it was not considered worthwhile to install a set of thermocouples because temperature data were available from similar tests already completed on tar-rubber. The same power cycle as that used on tar-rubber pavements was followed. Erosion started quickly after cutting in the afterburner (about 3 sec as compared to 5 sec on tar-rubber) and after 45 sec the eroded area was 51 ft by 9 ft by 3/4 in. This area is considerably larger than those for either of the tar-rubber test panels, being at least 3 ft longer, 2 ft wider, and 1/4 in. deeper.

Observations of Jet-fuel Spillage

34. During the course of the tests, spillage of fuel by the F-100 plane was observed. In normal operation without afterburner, about 1 to 2 pt of JP-4 fuel was spilled each time the engine was cut off just as on other types of U. S. Air Force jet planes. However, when operating with the afterburner and then with the latter cut off (engine kept running) about 1/2 gal of JP-4 fuel was spilled on the pavement. Spillage in both instances was from a cluster of drain pipes under the fuselage and about 40 in. above the pavement. The total quantity of fuel spilled at each of three locations (B, C, and D) was about 1.5 gal. There was

no visible effect on portland-cement concrete (location D) or on either of the two tar-rubber concretes (locations B and C). Only 0.5 gal of fuel was spilled at any one spot on asphalt. The pavement softened slightly but was substantially cured out and stable within 24 hours.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

35. On the basis of the results of the tests summarized herein and coupled with information available from previous investigations and inspection of pavements, the following conclusions appear warranted concerning the F-100A plane:

a. Maximum anticipated pavement surface temperatures for specific conditions are as follows:

(1) Blast at idle power, 200°F

(2) Pretake-off blast, 300°F plus

(3) Maintenance blast without afterburner, 295°F

(4) Maintenance blast with afterburner: 1.5 minutes at full power, 650°F; 5.0 minutes at full power, 735°F

b. Effect of heat and blast on pavements is as follows:

(1) Blast at idle power had no visible effect on any of the pavements tested.

(2) The pretake-off operations as followed in these tests had no deleterious effect on asphaltic-concrete, tar-rubber-concrete, or portland-cement-concrete pavements.

(3) The maintenance run-up without afterburner, as performed in these tests, had no deleterious effect on tar-rubber- or portland-cement-concrete pavements. The asphaltic-concrete pavement eroded to some extent under this long exposure period.

(4) The maintenance run-up with afterburner, as performed in these tests, quickly eroded asphalt and the two tar-rubber pavements. The same run-up did not erode portland-cement concrete, but discolored the area of intense heat and accentuated the surface crazing barely visible in that area prior to test.

Recommendations

36. The following considerations are offered concerning operations of the F-100A plane:

<u>a</u>. Further study is desirable regarding operations of afterburners on portland-concrete pavements, particularly where pavement-surface temperatures are in the range of 600 to 1500°F in the high-heat impingement area.

<u>b</u>. The four test areas at Davis-Monthan Air Force Base should be inspected within the next few months to check the condition of the pavements and such sampling and testing of pavements as appears warranted should be accomplished.

<u>c</u>. Consideration should be given to the probable necessity of providing several special areas at each Air Force base which will withstand sustained afterburner blast. The initial unit cost of such areas would be appreciably greater than normal portland-cement concrete, but since the number and extent of such areas would be quite limited, the over-all cost increase would be negligible. These special areas should be provided with heavy-duty anchoring facilities.

d. Proper precautions should be taken in regard to jet-fuel spillage to prevent damage to asphaltic-concrete parking and maintenance aprons.

Table 1

Pavement Temperature Measurements, Davis-Monthan Air Force Base, Tucson, Arizona

Plane Type F-100A(1)

Test No.	Simulated Operation	Blast Duration min:sec	Pavement Type	Date	Time	Amb Temp deg F	Wind Velocity and Direction mph	Measured Height ℄ of Tailpipe Static, in. (Rated 58)	Distance Tailpipe to Thermocouple ft	Max Temp Observed on Pavement deg F	Pavement Temp at Start deg F	Temp Rise from Blast deg F	Remarks
D-1	Pretake-off	1:17(2)	Concrete	7-15-54	0850	98	12 ESE	58	31	300+(7)	110	190+	No visible change from original surface condition.
D-2	Maint w/o afterburner	24:30(3)	Concrete	7-15-54	0915	98	12 ESE	58	31	295	130	165	No visible change at surface except for slight darkening from exhaust gases.
D-3	Maint with afterburner	24:30(4)	Concrete	7-15-54	1400	103	12 ESE to SE to S	58.5	31	735	150	585	No visible change at surface except brown appearance after intense heat over area about 4 ft x 15 ft and accentuated minute crazing(10).
C-1	Pretake-off	1:17(2)	Flintbinder C-2	7-14-54	1530	100	6 NE	57.75	31.5	300+(7)	130	170+	Very slightly melted surface giving dark appearance to area about 2 ft x 18 ft but no erosion.
C-2	Maint w/o afterburner	24:30(3)	Flintbinder C-2	7-14-54	0950	91	Calm	59	31.5	280	110	170	No visible change from original surface condition.
C-3	Maint with afterburner	6:25(5)	Flintbinder C-2	7-14-54	1600	99	16 NW	57.75	31.5	685(8)	150	535	Erosion started about 5 sec after cutting in the afterburner and after 45 sec the eroded areas were 45 ft x 6 ft x 1/2 in.
B-1	Pretake-off	1:17(2)	Surfa-Aero-Sealz	7-13-54	0630	72	4 [illegible]	59	31	300+(7)	95	205+	Same as for test C-1.
B-2	Maint w/o afterburner	20:30(6)	Surfa-Aero-Sealz	7-13-54	0700	74	5 [illegible]	59	31	265	110	155	No visible change from original surface condition.
B-3	Maint with afterburner	6:25(5)	Surfa-Aero-Sealz	7-14-54	1415	99	6 N	57	31	680(8)	130	550	Erosion started about 5 sec after cutting in the afterburner and after 45 sec, the eroded area was 48 ft x 7 ft x 5/8 in.
A-1	Pretake-off	1:17(2)	Asphalt	7-14-54	1115	98	Calm	58.5	31	(9)	---	---	Same as for tests C-1 and B-1.
A-2	Maint w/o afterburner	24:30(3)	Asphalt	7-14-54	1045	96	Calm	58.5	31	295	140	155	See (11) below.
A-3	Maint with afterburner	6:25(5)	Asphalt	7-14-54	1645	99	16 NW	57	31	(9)	---	---	Erosion started about 3 sec after cutting in the afterburner and after 45 sec, the eroded area was 51 ft x 9 ft x 3/4 in.

Note: (1) Angle of tailpipe rated at 6°24' static 6°09' at idle power, 95 per cent, 5°22' at military power, and 5°10' at full power (with afterburner). Height of center line of tailpipe rated at 58 in. static and 61 in. at military power. Effective diameter of end of tailpipe is 22 in. without afterburner and 23 in. with afterburner. Play in nose wheel strut about 3 in. and in load wheel struts about 11 in. Engine is model J57-P-7 producing thrust of 9,600 lb at military power and 13,000 lb at full power with afterburner. Tests by plane manufacturer show gas velocities at distance of 30 ft aft of tailpipe to be 469 and 689 ft/sec for military and full power, respectively. Corresponding gas temperatures 1.5 in. above pavement are 388 and 912° F.

(2) One minute at idle power, 15 sec at military power, and 2 sec at full power.
(3) 5.5 min at idle power, 1.5 min at military power, 5.5 min at idle power, 1.5 min at military power, 5.5 min at idle power, and 5 min at military power.
(4) 5.5 min at idle power, 1.5 min at full power, 5.5 min at idle power, 1.5 min at full power, 5.5 min at idle power, and 5 min at full power.
(5) 5.5 min at idle power, 15 sec at military power, and 45 sec at full power (test stopped owing to pavement failure).
(6) 5.5 min at idle power, 1.5 min at military power, 5.5 min at idle power, 1.5 min at military power, 5.5 min at idle power, and 1 min at military power (tailpipe indicating hot).
(7) Maximum temperature for brief period of about 2 sec of blast with afterburner could not be accurately determined with 12-pt recorder but appeared to be between 300-400° F in all cases.
(8) Gas temperature rather than temperature of surface of pavement since thermocouples were about 1/2 in. above pavement owing to erosion.
(9) Pavement failed at original instrumented test area. New section used for these tests and no thermocouples installed.
(10) The original crazing is attributed to improper curing, prevalent to a degree on other areas of the concrete apron.
(11) Minor flaking at surface during first blast at military power when pavement temperature at surface reached 290° F. Limited erosion at surface during second blast at military power when pavement temperature at surface reached 295° F. Definite erosion at surface during third blast at military power when pavement temperature at surface again reached 295° F. This erosion was definite within the 1.5 min military power cycle normally used in a maintenance blast. Erosion was noted at three thermocouple locations where temperatures being recorded were 295° F. The test was continued for an additional 3.5 min at military power with total eroded area measuring 15 ft x 3.5 ft x 1/2 in.

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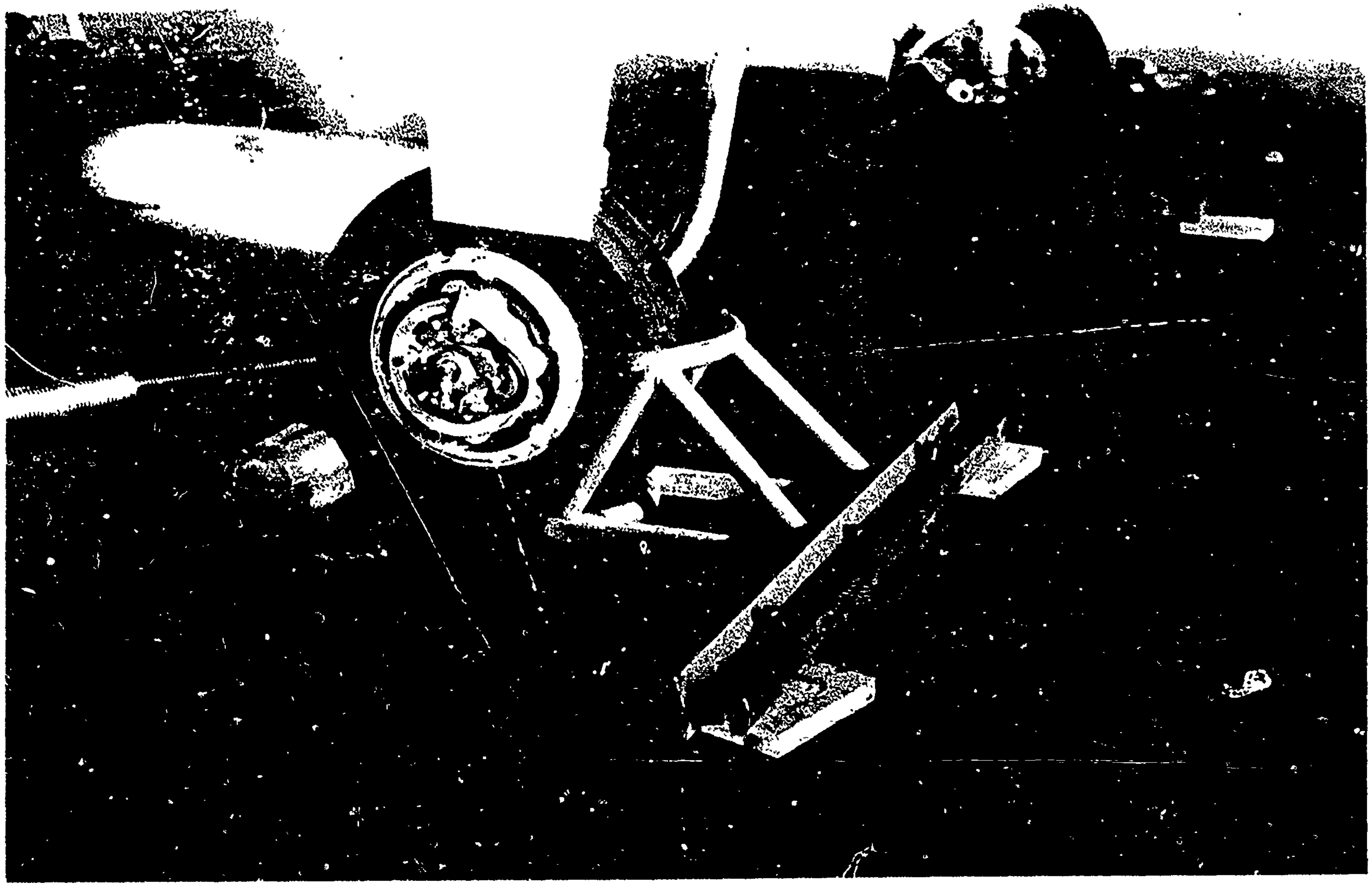
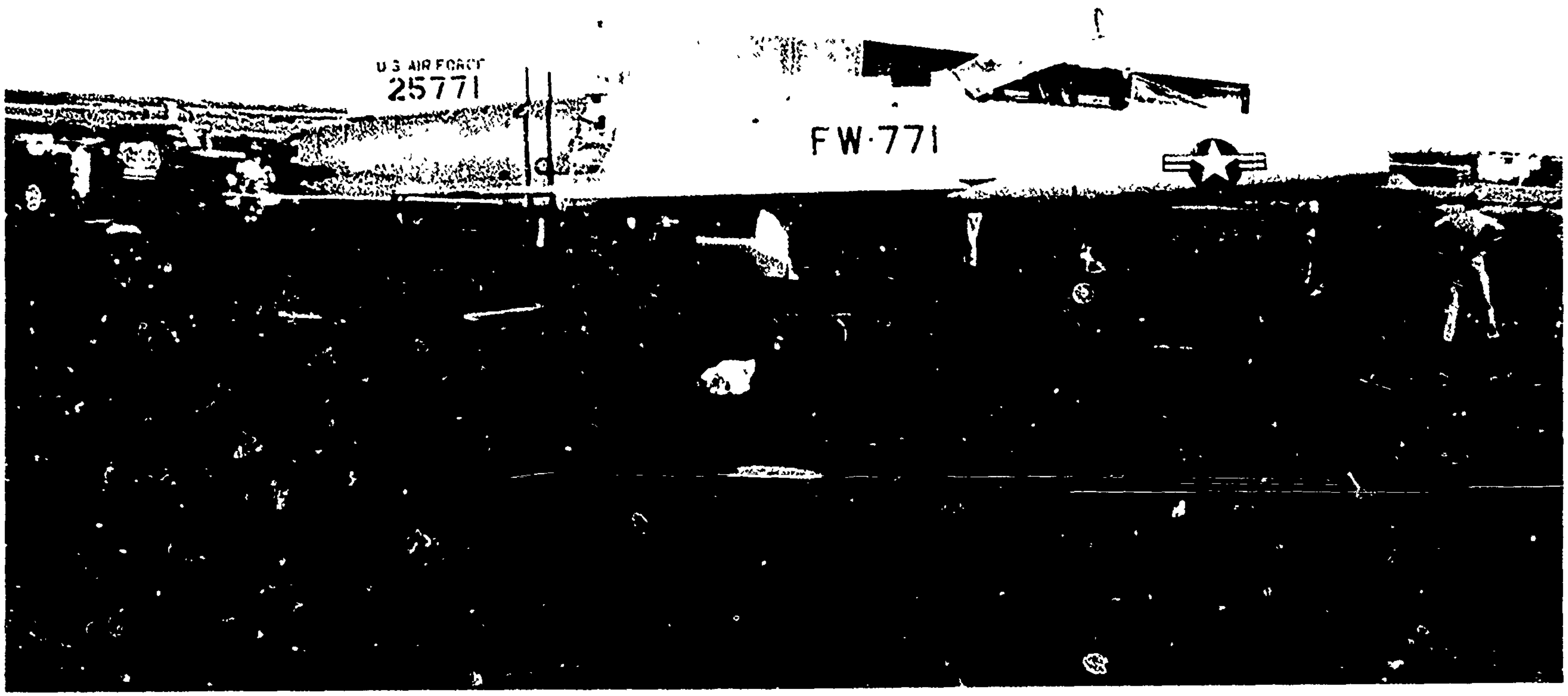
PHOTOGRAPH 1



Special chalks and anchors for F-100 plane

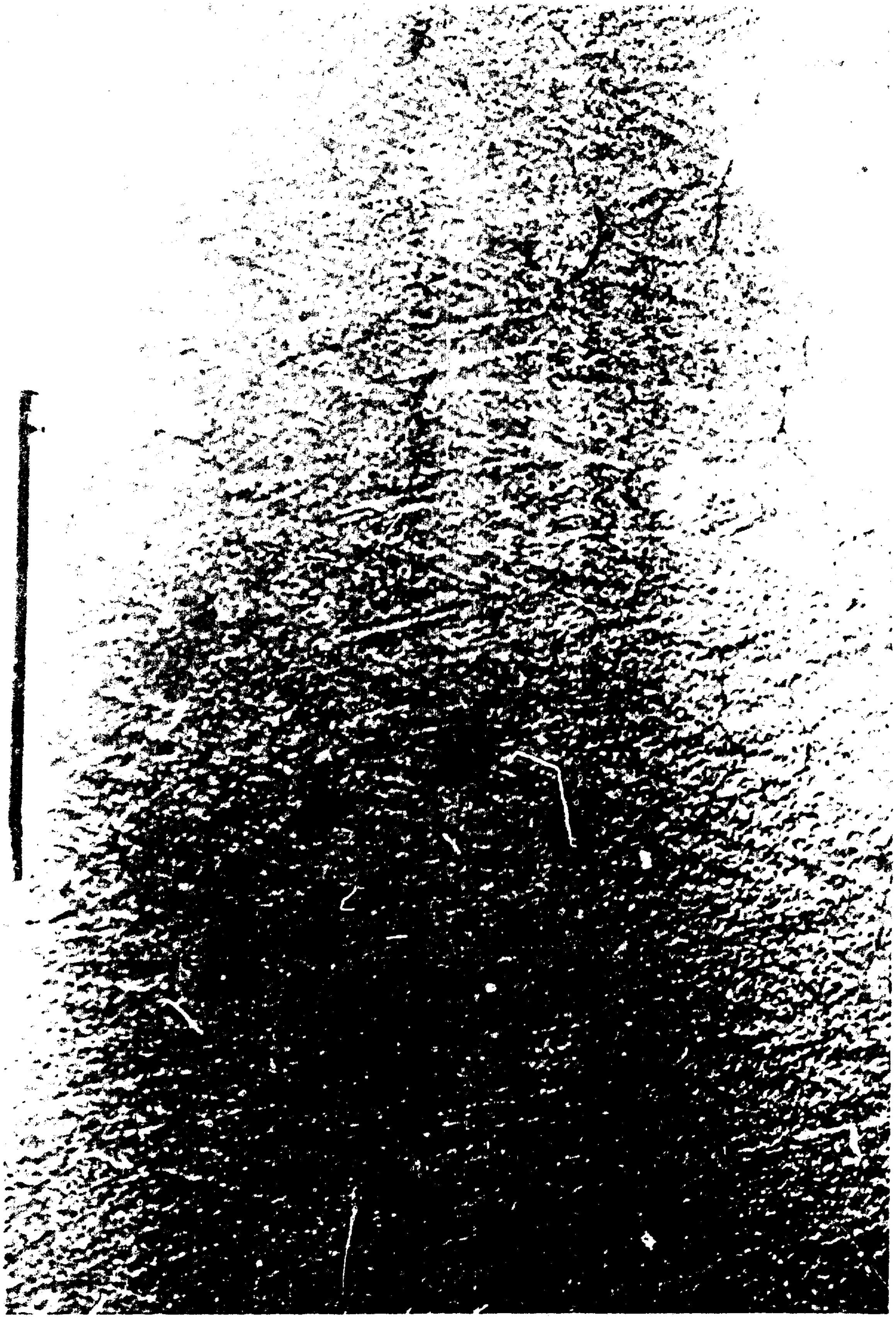


Side view of F-100 plane and accessory equipment set up for test

PHOTOGRAPH 2

Portland-cement concrete after maintenance blast with afterburner

PHOTOGRAPH 3



Accentuated surface crazing on portland-cement concrete after 8 min of blast with afterburner

PHOTOGRAPH 4

Tar-rubber (Surfa-aero-sealz) eroded after 45 sec of blast with afterburner

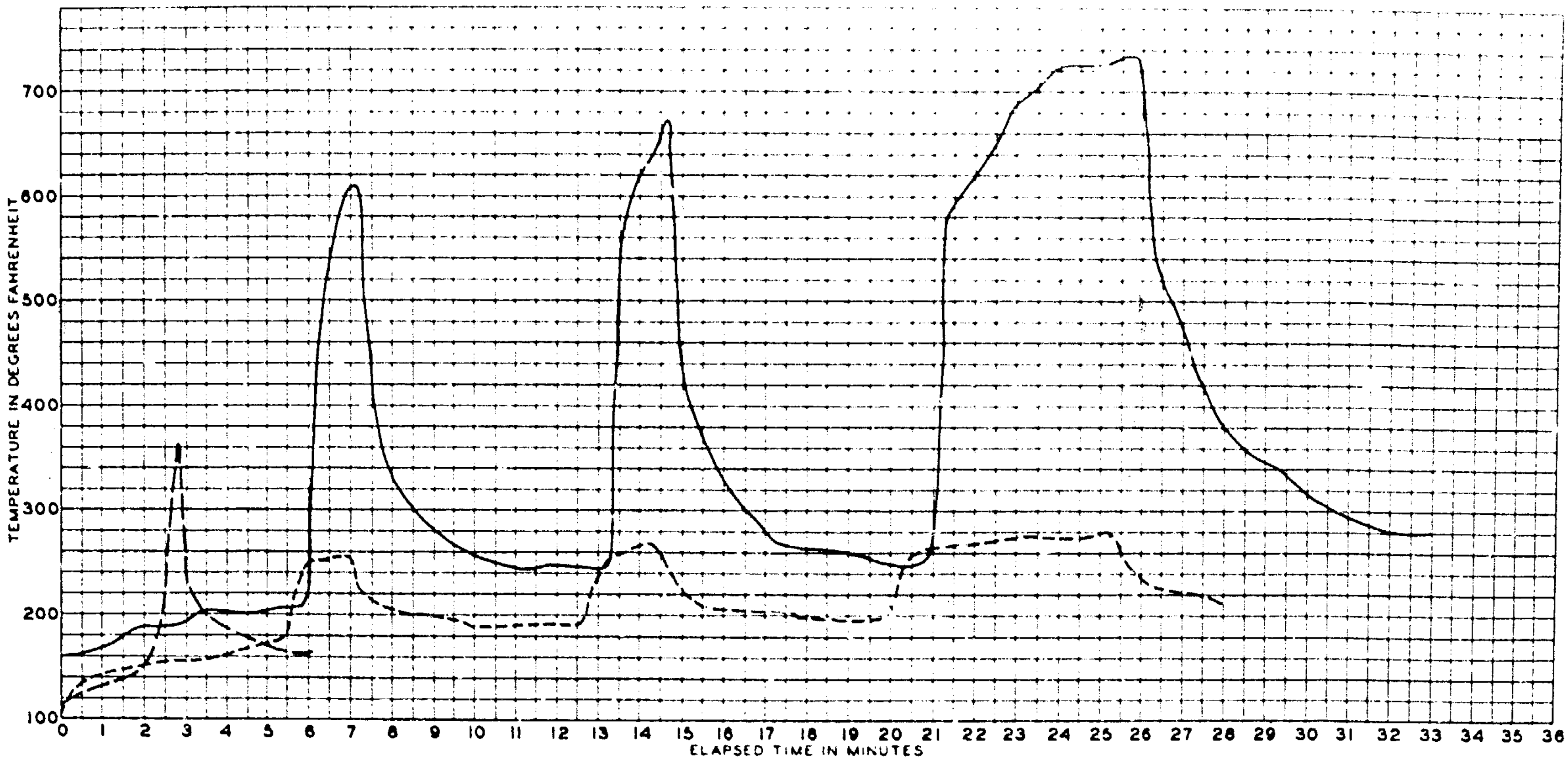
PHOTOGRAPH 5

Asphalt darkened after pretake-off blast (1-2 sec with afterburner)

PHOTOGRAPH 6

Asphalt eroded after maintenance blast without afterburner (8 min at military power)

PHOTOGRAPH 7



LEGEND

MAINTENANCE BLAST WITH AFTER BURNER
MAINTENANCE BLAST WITHOUT AFTER BURNER
PRETAKE-OFF BLAST

NOTE: PEAK OF CURVE FOR PRETAKE-OFF BLAST INDEFINITE OWING TO SLOW RESPONSE OF RECORDER AND SHORT BLAST AT FULL POWER

TYPICAL TEMPERATURE VS TIME
F-100 A PLANE

072154 A

PLATE I

PARTICIPANTS AND OBSERVERS - F-100 BLAST TESTS

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Mr. L. R. Hovater	" " " " " "